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Venus Aerobot Multisonde Mission: Atmospheric Relay for Imaging the Surface of Venus

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Abstract:

Robotic exploration of surface of Venus presents many challenges because of the thick atmosphere, high surface pressure and temperature. The Venus Aerobot Multisonde Mission concept addresses these challenges by using a robotic balloon or aerobot to deploy a number of short lifetime probes or sondes to acquire images of the surface, perform atmospheric measurements and measure a fine composition of the atmosphere. Deployment of sondes from an aerobot has two compelling advantages – it permits more precise deployment than with direct entry and it makes it possible to acquire high-rate data from the sondes using very low power transmitters because of the short communications ranges of a few tens of kilometers. Sonde data stored on the aerobot can be communicated at much lower rates from the aerobot that will operate for at least a week in the Venus atmosphere. This paper describes the Venus Aerobot Multisonde concept which is a foundation for Venus Exploration of Volcanoes and Atmosphere (VEVA) - a proposal to NASA's Discovery program. Besides discussion of aerobot performance the paper deals with communications and navigation issues and sondes' instrumentation that are key factors for the mission success.

INTRODUCTION

In spite of a number of successful missions to observe the surface and interior of Venus, a number of fundamental questions about the planet have yet to be resolved. The Venus Geoscience Aerobot (VGA) concept developed in 1995-1997, would make multiple excursions from high altitude in the Venus atmosphere to conduct observations at or near the surface in order to address these questions. The VGA requires a number of new technologies (Ref 1) including high temperature balloon materials, gondola thermal control systems and reversible fluid altitude control that will require a significant investment and at least five years of development. The VGA also requires an orbital relay system that significantly increases the overall mission cost.

The Venus Aerobot Multisonde (VAMuS) Mission was conceived to provide many of the scientific capabilities of the VGA, with existing technology and without requiring an orbital relay that would result in significant reduction of the mission cost. It consists of two-three autonomous floating stations (aerobots) which would deploy 4 to 6 dropsondes equipped to acquire high resolution science data from near the Venus surface. Data would be communicated from the sondes to the floating station and relayed from there to Earth. The total mission cost is believe to be well within the scope of a Discovery mission. In this paper, we describe the VAMuS mission concept with emphasis on navigation and communication aspects of the mission.

VENUS AEROBOT MULTISONDE MISSION CONCEPT:

The environment of Venus present major challenges for scientific exploration. A thick atmosphere of carbon dioxide, with a surface pressure of 92 bars and clouds and haze in the upper reaches totally obscures the planets surface from remote observation from orbit except using radar imagery. The vertical structure of the atmosphere of Venus is shown in Fig.1.

Fig.1. Vertical structure of the Venus atmosphere

The surface temperature is about 460 °C and therefore long duration surface vehicles for in situ investigation require radioisotope powered refrigerators or high temperature electronics or both and become complex and extremely costly. Short duration observations in the lower atmosphere using either small expendable sondes that maintain their contents at the operating temperature of conventional electronics through passive thermal protection for a few hours are a much more attractive solution. However, to be effective as an exploration tool, these sondes must be able to communicate large amounts of data during their limited lifetime. In particular, it is desired to acquire high resolution aerial imaging from near the surface of the planet for a number of targets of high scientific interest.

At the same the environment in the upper atmosphere is quite mild and the atmosphere of Venus above 52-53 km resembles the atmosphere of Earth except for presence of sulfuric acid haze-like clouds. With permanent clock-wise 65-100 m/s winds this region provides many advantages for the aerobots. However, because of clouds, hazes and Releagh scattering the surface of Venus can not be seen from this altitude at leawst in visible band.

The innovative feature of the VAMuS mission is to use aerobots(balloons) flying at 55-60 km altitude as both a *delivery system* and a *high data rate communications relay* for multiple low cost imaging dropsondes. By using an Aerobot delivery and relay system it is possible to deliver more sondes with higher accuracy and with higher data return than when sondes are delivered to Venus by direct entry. The VAMuS mission concept is illustrated in Figure 2.

Fig.2. Venus Aerobot Multisonde (VAMuS) mission concept

Each aerobot upon emplacement consists of gondola and dropsondes suspended from a superpressure balloon. The balloon maintains the vehicle on a surface of constant atmospheric density in the Venus atmosphere except for perturbations caused by downdrafts and probe deployments. Superpressure balloon deployment and inflation was successfully demonstrated in 1985 in the Venera Vega balloon mission. Each of two Venera Vega balloons was tracked for two days in the Venus atmosphere. More recently, in August 1998, JPL demonstrated an aerial deployment and inflation of the Vega size balloon but made of material 17 times lighter. This demonstration enables a modern high payload mass fraction aerobot missions to the planets with the dense atmosphere (Venus and Titan at the first hand).

Sonde Deployment: Aerobot deployment makes it possible to sequence deployments and target sondes based on what has already been learned from earlier missions. A radar map of Venus was obtained by the U.S. Magellan mission in the 1980s and allows important scientific target to be identified. From a float altitude of about 60 km, the sondes can be dropped with an accuracy of a few 10s of km which is much better than could be achieved from a direct entry.

After deployment from the aerobot, each sonde will descend rapidly towards the surface. At an altitude of a few kilometers, the descent is arrested by a parachute or gliding device that permits an extended data acquisition near the Venus surface. Carried by the fast westward high altitude winds the aerobot will be carried rapidly to the west of the probe. Based on initial analysis, the descent speed of the sonde, the thermal survival time and the period for which the floating station remains within visibility of the sonde are roughly commensurate permitting about 15-30 minutes of high rate imaging data near the surface..

Communications The proximity of the aerobot to the sondes provides high data rate communications at rates of the order of 1 Mb/sec. These data must then be stored on the aerobot and communicated to earth with a directional antenna to provide high performance communications with Earth at rates of order 10 kb/sec. There is no requirement for the use of a relay spacecraft or orbiter at Venus which reduces the cost and complexity of the mission.

VEVA MISSION OVERVIEW

The VEVA mission involves the delivery of two identical payloads to Venus. Each entry vehicle consists of an large sonde designed for atmospheric measurements and a balloon/gondola system. An aerodynamic heat shield encloses the payload and provides initial g load protection and support for the entry phase. After entry, the heat shield is jettisoned, the atmospheric sonde begins its fall to the surface and the balloon inflates, which arrests its descent and then provides lift to maintain a 60-km float height. The balloon carries an instrumented gondola with battery power for 7 days as it circles Venus. Each gondola carries four small (imaging) sondes for release at different times during the mission. Several kinds of science measurement are made

- The two large sondes are released from their respective gondolas on entry and fall to the surface in about 37 minutes. They measure composition below 20 km altitude to the surface and an integrated suite of instruments provide a detailed characterization of the atmosphere.
- The eight smaller sondes free falls to 5 km above the surface where a small gliding parachute opens to slow the descent and provide horizontal offsets between successive images. These imaging sondes also carry an integrated atmospheric physics sensor suite to measure ambient conditions. Each sonde will be equipped at a minimum with an imaging system. The feasibility of an integrated imager, laser altimeter and spot spectrometer is being explored. Initial indications are that once below 5 km the contrast attenuation produced by the Venus atmosphere for albedo features is less than a factor of 5. Consequently, features in the Magellan imagery will be readily recognizable for putting the probe data in context.. Imaging of high quality and spatial resolution will be acquired beneath 2km altitude Measurements of the chemistry in the low atmosphere is another key objective and micro-miniaturized mass spectrometers are being examined for this application
- The gondola also carries an atmospheric physics suite to measure ambient conditions at the 60 km altitude for a period of up to 7 days an will use a magnetometer to seach for solar wind produced and intrinsic magnetic fields Radio tracking with the Deep Space Network will be used for precise measurements of horizontal winds

The primary communications mode for both large and small sondes is through the balloon. A low data-rate S-band system can be used to derive positional and wind information from the ground-based VLBI and Doppler measurements.

Parameters of the sonde descend and of the relative motion of the aerobot and the sonde are shown in Fig.3. When the sonde approaches the surface the distance to the aerobot is about 90 km. In the next 20 min it grows to 200 km. At this time an elevation angle of the aerobot is ~ 17 deg. Due to the atmospheric refraction the communications with the aerobot can be supported much longer.

Fig. 3. Parameters of the sonde descend and of the relative motion of the aerobot and sonde

COMMUNICATIONS

Such a short distance (220 km in comparison with ~130 mln km to the Earth) enables high-data rate transmission from the sonde to aerobot with a simple low-power UHF link of the type using in the Mars mission.

The link budget at the maximum distance between the dropsonde and aerobot is shown in Table 1.

Table 1.

Parameter	**Units**	**Value**
Transmitted power	W	1.0
Dropsonde antenna gain (monopole at 20° elevation)	dB	1
Frequency	MHz	400
Range	km	220
Atmospheric absorption losses	dB	-1
Receiving antenna gain (monopole at 70° nadir angle)	dB	1
RX system temperature (including Venus surface thermal radiation)	K	900
Received power	dBm	-101.8
SNR	dB-Hz	66.8
Bit rate	kbit/s	512
Threshold (7,1/2 convolutional code)	dB	4.5
Link margin	dB	5.6

This link would allow to transmit one frame 1024x1024 pixels in ~20 s; total amount of high-resolution low-altitude pictures will ~45-60 from each sonde. Total volume of data from all sondes ~2.5 Gbit. A mild data compression (1:3) on the aerobot will reduce this volume to ~830 Mbit.

The feature of the concept is use of the articulated high-gain X-band antenna on the aerobot to relay the imaging data to the Earth. The Mars Pathfinder flat array antenna used as the prototype. The link budget for direct-to-Earth link is given in Table 2.

Table 2.

Parameter	**Units**	**Value**
Transmitted power	W	10
Aerobot antenna gain	dB	24.6
Frequency	MHz	8430
Range	Mln km	150
Atmospheric absorption losses (aerobot at 60 km)	dB	-0.2
Receiving antenna gain	dB	74.1
RX system temperature (including Venus surface thermal radiation)	K	51
Received power	dBm	-136.5
SNR	dB-Hz	45.0
Bit rate	kbit/s	10
Threshold (turbo code)	dB	0.9
Link margin	dB	4.1

It is needed ~24 hrs to transmit all data from the dropsondes.

The aerobot antenna beamwidth is ~10^{o} and the antenna needs to be pointed in the Earth direction with accuracy <2^{o}. The signal transmitted by the DSN stations will be used as a beacon to find the Earth direction. During the free flight the aerobot, moving with the wind, remains exceptionally stable in the vertical direction. It can slowly rotate along the vertical axis (typical rotation period exceeds 20-40 min). After initial acquisition of the Earth stable a simple one-dimensional antenna tracking will be needed to maintain communications.

Doppler, range and VLBI measurements will be used to determine position and drift of the aerobot and to target the dropsondes. The expected accuracy is less than 10 km.

TECHNOLOGY FOR VENUS MICROSONDE MISSIONS:

Here we review the status of some of the key technologies needed for such mission..

Balloon Deployment and Inflation: After separation from the aeroshell, the descent velocity of the VEVA payload elements is reduced by a 7-m diameter parachute. The thick Venus atmosphere provide ample time to deploy and inflate the robustly designed balloon. After the atmospheric sonde is released, the balloon container opens and the balloon extends with the gondola and inflation system suspended below. A ripstitch mechanism absorbs the impact of the deployment. A low friction swivel and a long riser between the parachute and the balloon prevent twisting motion of the balloon. Gas is injected through the bottom of the balloon using a diffuser and windsock developed in a recent JPL technology development program. This bottom inflation system dramatically improves the aerodynamic stability of the system, eliminates problems with the parachute separation and provides a substantial gain in payload fraction over the top inflation system used on the VEGA mission.

A prototype deployment and inflation system has been tested in a relevant environment in a helicopter drop test conducted in cooperation between JPL and Dryden Flight Research Center in California's El Mirage Dry Lake in August 1998. Atmospheric pressure and gravity field are very similar to those that would be encountered at Venus. The series of frames in Fig. 4 shows the descent of the payload beneath a parachute, deployment of the balloon envelope with ripstitch shock absorber and inflation of the balloon. The balloon envelope stabilized rapidly after deployment and inflation was initiated successfully 16 sec later without rotation of the balloon envelope occurring.

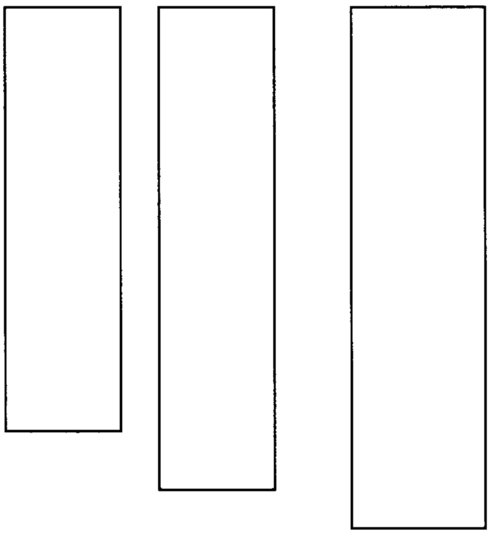

Fig. 4. Low-altitude deployment and inflation test of 3-m diameter Mylar balloon

Balloon Envelope Technology: Compared to other Venus Aerobot missions, the Venus Geoscience Aerobot (VGA) and the Venus Sample Return (VESAR), the balloon requirements for Venus Multisonde missions are less demanding because the balloon only operates at high altitudes at temperatures –20…0C. The materials must still survive passes through sulfuric acid haze clouds. In one sense this is a proven technology because the Venus VEGA balloons operated successfully for the 2 day duration required for VEVA mission for example. However, a heavy teflon cloth used in the VEGA balloons would make unreal the VEVA mission.
Two concepts for such a balloon have been devised. Both seem feasible and the choice will be an engineering decision. One of them is a bilaminated mylar (23 umX 23 um) balloon with a kevlar scrim reinforcement and a teflon sheath. It has been tested and shown to tolerate the sulfuric acid effects. An alternative balloon material is polyethylene/mylar laminate. Recent tests confirmed that polyethylene is resistant to sulfuric acid.

Sonde Technology: Development of technology for short duration trips to the near surface of Venus was originally motivated by the needs of the Venus Geoscience Aerobot (VGA) mission. This mission will use capabilities developed in a number of technology programs, the current ground based planetary aerobot validation program and New Millennium DS 2. At this time there are no new enabling technologies that are required for this mission. Some new enhancing technologies may be utilized but not where risk in their use compromised overall mission goals.

New instrumental techniques will be important in broadening the scope of the scientific questions that can be addressed.

A concentric sphere design was selected with the 38cm outer sphere taking the external pressure load and a 15.6 kg dummy payload housed inside a 30 cm diameter inner sphere. The concentric sphere design was selected to permit vacuum insulation between the two spheres. It was later determined that fiberglass insulation filled with a low conductivity gas – nitrogen or xenon – is almost as effective as vacuum insulation given the other parasitic losses. A prototype unit was built (Fig 2) and tested both the Measured heat leaks on the prototype were 111W for xenon and 256W for nitrogen. Pressure tests were successfully performed to 9.2 Mpa. Prior to a final test leaks were found in the gondola seal but these are believe to be associated with cyclic pressure and temperature variation. A final test was a 250 g centrifuge test which was completely successful with post test inspection revealing no damage or plastic deformation of gondola components.

On the basis of these tests designs for both the large sonde and the small sonde were developed. A prototype thermal test model of the imaging (small) sonde is not being built to these specifications. We are also drawing on experience with the Europa Vostok program for developing the window technology needed for the small sonde.

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